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TITLE: NUMERICAL MODELING FROM MESOSCALE TO URBAN SCALE TO BUILDING SCALE

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8.1 NUMERICAL MODELING FROM MESOSCALE TO URBAN SCALE TO BUILDING SCALE

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1. INTRODUCTION

For plumes originating in urban areas, the larger-scale transport may depend on the near-source dispersal patterns within the city. In addition, the near-source dispersal behavior within the urban canopy may depend on the larger-scale flow features. In this paper, we will present preliminary meteorological and tracer dispersion simulations from a hierarchy of three prognostic models that were centered around Salt Lake City, Utah. The mesoscale COAMPS, the urban-scale HIGRAD, and the building-scale FEM3MP models were used to perform the simulations in a nested configuration. The multi-scale modeling approach allows us to explicitly capture mesoscale flow features over the large domain as well the effects of individual buildings in the smaller area of interest. At the conference, we will discuss an early morning and an afternoon simulation case and evaluate the effects of stability on transport and dispersion on the urban and building scales. We also will study whether or not the dispersion over the mesoscale is sensitive to what happens on the building scale.

2. BACKGROUND

There have been many simulations of flows around buildings (e.g., Murakami, 1993; Calhoun et al., 2000) and on the mesoscale that have included urban canopy effects (see review by Brown, 2000). Fewer simulations have been performed linking building-scale and mesoscale models (e.g., Brown and Müller, 1997; Cox et al., 2000), and even fewer have been conducted that explicitly simulate the flow on the individual building scale, the many-building urban scale, and the mesoscale. Below we describe a collaborative effort between Lawrence Livermore and Los Alamos National Laboratories in which a system of models are linked through boundary conditions in order to study a problem from the large mesoscale down to the building scale.

3. MODEL DESCRIPTIONS & SETUP

a) COAMPS. The Naval Research Laboratory's 3-D "Coupled Ocean/Atmosphere Mesoscale Prediction System" solves the geophysical fluid equations for atmospheric momentum, heat transport, moisture, and surface energy budget. COAMPS consists of a data assimilation system, a nonhydrostatic atmospheric forecast model, and a hydrostatic ocean model. In this study, we use only the atmospheric model, which solves the compressible form of the dynamical equations and has a nested-grid capability and parameterizations for subgrid-scale mixing, surface momentum and heat fluxes, explicit ice microphysics, subgrid-scale cumulus clouds, and shortwave and longwave radiation. A terrain-following vertical coordinate is used to simulate flow over an irregular surface. An urban canopy parameterization is incorporated (Chin et al, 2000). The reader is referred to Hodur (1997) for further details on COAMPS.

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b) HIGRAD. The "High Gradient" model solves the 3-d Navier-Stokes equations in a terrain-following coordinate system. The model is second-order accurate and uses a non-oscillatory forward-in-time advection scheme that can accurately model regions of strong shear. The model can be run in an anelastic mode using an efficient conjugate residual pressure solver or in a compressible mode using the method of averages. Turbulence closure is accomplished using a Smagorinsky-type or a TKE-based large eddy simulation (LES) scheme. The code solves a surface energy budget equation and includes shading effects. Further information can be found in Reisner et al. (1998).

c) FEM3MP. The "Finite Element Model 3 - Massively Parallel" solves the 3-d Navier-Stokes equations. An anelastic approximation allows the model to simulate a wide range of stability conditions. An implicit time discretization scheme means that larger timesteps can be taken. The model incorporates an advanced multigrid Poisson solver. There are two principal turbulence models: a LES Smagorinsky turbulence model with a special treatment of the subgrid length scale in the presence of buildings and a three equation RANS model which contains many of the features of second-order closure. A more thorough description of the FEM3MP model can be found in Gresho and Chan (1998).

d) Setup. The COAMPS model utilized a 36, 12, and 4 km resolution nested grid mesh and was run for a 36 hour forecast with a begin time of 5:00 am Dec. 9, 1999. The outermost mesh covered the western US, while the innermost mesh covered a 240x240 km area in the Salt Lake City basin. Wind, temperature, and humidity profiles computed by COAMPS were used to drive the HIGRAD urban-scale simulation. Results presented in this paper represent a simulation covering a 1.6x1.5 km domain in downtown Salt Lake City with 10 m grid size. Simulations performed over a 100 km domain with a variable horizontal grid resolution of 10 to 500 meters will be presented at the conference. HIGRAD-produced meteorological profiles were then used to drive the FEM3MP model at grid resolutions on the order of meters. Here, the flow field around individual buildings was resolved at high resolution. Below we show examples of these simulations at each scale.

4. DISCUSSION

Figure 1 shows the COAMPS-computed wind field on the innermost mesh at 10m agl for 5 am, Dec. 10, 1999. Drainage flow has developed due to the mountains and stagnation occurs over the city. With the urban canopy parameterization turned off, the urban area does not impede the drainage flow and the stagnation zone is less evident. Vertical profiles of velocity, temperature, and turbulent kinetic energy over the city are altered significantly by the urban canopy.

Vertical profiles of spatially-averaged COAMPS wind, temperature, moisture and tke over one grid cell in the Salt Lake City area for 5 am were used as the boundary conditions for the HIGRAD code. Here we assumed that the meteorological fields did not change appreciably over the 1 hour period of HIGRAD simulation. Figure 2 shows the wind fields at 10 m agl over the southeastern quadrant of the domain for 6 am. Clearly, very complicated wind patterns have developed among the irregularly arranged group of buildings.

The HIGRAD wind and turbulence fields were area- and time averaged and vertical profiles provided to FEM3MP. Figure 3 shows a steady-state solution for the wind field around the Delta Center in Salt Lake City. A double vortex forms on the downstream side which is slightly skewed due to the presence of the 2 small buildings. Simulations of tracer dispersion were performed at each scale and will be presented at the conference.

5. CONCLUSIONS

We have presented a demonstration of linking model simulations across the mesoscale, urban scale, and building scale. Our preliminary results illustrate the effects of including urban areas on the locally forced, mesoscale wind fields, and at finer scales of including individual buildings and building clusters. As we continue this work, we will include time-dependent and spatially-varying boundary effects.

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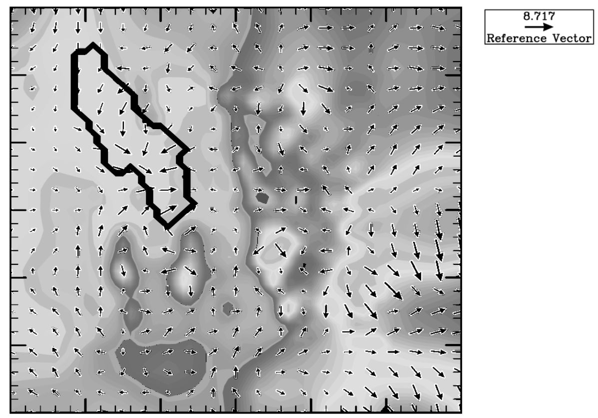

Figure 1. COAMPS simulation showing wind vectors in the Salt Lake City basin.

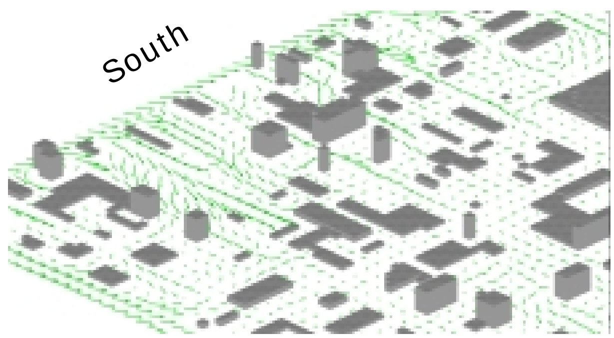

Figure 2. HIGRAD simulation showing wind vectors around downtown Salt Lake City.

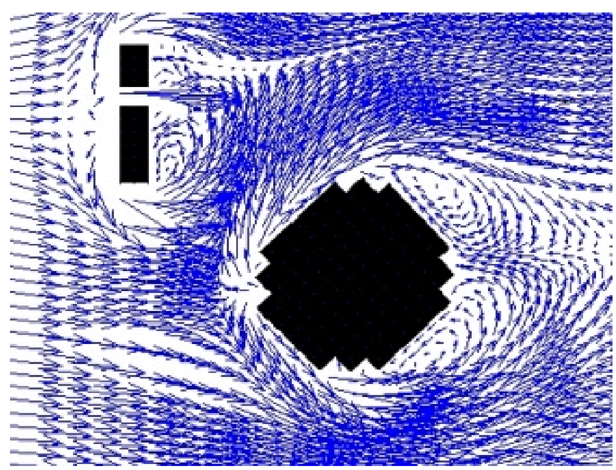

Figure 3. FEM3MP simulation showing wind vectors around the Delta Center.